APPENDIX D
STREAMFLOW, SEDIMENT, AND NUTRIENT SIMULATION ON THE BLACKFOOT WATERSHED USING SWAT

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Model Description

The Soil Water Assessment Tool (SWAT) model was originally developed by the USDA ARS to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large ungaged basins (Arnold et al., 1998). SWAT incorporates features of several ARS models and is a direct outgrowth of the SWRRB model (Simulator for Water Resources in Rural Basins) (Williams et al, 1985). Specific models that contributed to the development of SWAT include CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al., 1987), and EPIC (Erosion-Productivity Impact Calculator) (Williams et al., 1984). The SCS runoff curve number is used to estimate surface runoff from daily precipitation (USDA SCS, 1986). The curve number is adjusted according to moisture conditions in the watershed (Arnold et al, 1993). SWAT can also be run on a sub-daily time step basis using the Green and Ampt (Green and Ampt, 1911) infiltration method. Other hydrologic processes simulated by the model include evapotranspiration; infiltration; percolation losses; channel transmission losses; channel routing; and surface, lateral, shallow aquifer, and deep aquifer flow (Arnold and Allen, 1996). The runoff curve number option (Neitsch et al, 2002) is adopted in this study. Evapotranspiration (ET) in SWAT is computed using the Priestly Taylor (Priestly and Taylor, 1972), Penman-Monteith (Allen et al., 1989) or Hargreaves (1975) method. For this study, the Hargreaves (1975) method was used to estimate potential ET, since extraterrestrial radiation and air temperature were the only two measured variables required for computing daily potential ET values with this method. Channel routing in SWAT is accomplished by either the variable storage or Muskingum routing methods. For this study, the variable storage method was used to route flows in SWAT.

SWAT is a distributed parameter model that partitions a watershed into a number of subbasins. Each subbasin delineated within the model is simulated as a homogeneous area in terms of climatic conditions, but with additional subdivisions within each subbasin to represent various soils and land use types. Each of these subdivisions is referred to as a hydrologic response unit (HRU) and is assumed to be spatially uniform in terms of soils, land use, topographic, and climatic data.

AVSWAT 2003 was the version of the model used in this study, which incorporates an ArcView GIS interface for expediting model input and output (Di Luzio et al., 2002). The ArcView GIS raster based system consists of a modular structure that contains a tool for optimizing the definition and segmentation of a watershed and network based on topography. It also consists of a tool for defining the HRUs over the watershed and an integrated user-friendly interface. The GIS interface not only allows users to segment a watershed, but to import and format the supporting data necessary for the specific application and calibration of the model.

AVSWAT 2003 also includes a multi-objective, automated calibration procedure that was developed by Van Griensven and Bauwens (2003). The calibration procedure is based on a shuffled complex evolution algorithm (SCE-UA; Duan et al., 1992) and a single objective function. In a first step, the SCE-UA selects an initial population of parameters by random sampling throughout the feasible parameter space for "p" parameters to be optimized, based on given parameter ranges. The population is partitioned into several communities, each consisting of "2p+1" points. Each community is made to evolve based on a statistical "reproduction process" that uses the simplex method, an algorithm that evaluates the objective function in a systematic way with regard to the progress of the search in previous iterations (Nelder and Mead, 1965). At periodic stages in the evolution, the entire population is shuffled and points are reassigned to communities to ensure information sharing. As the search progresses, the entire population tends to converge toward the neighborhood of global optimization, provided the initial population size is sufficiently large (Duan et al., 1992). The SCE-UA has been widely used in watershed model calibration and other areas of hydrology such as soil erosion, subsurface hydrology, remote sensing, and land surface modeling and has generally been found to be robust, effective, and efficient (Duan, 2003).

In the optimization scheme developed for SWAT 2003, parameters in the model that affect hydrology or water quality can be changed in either a lumped (over the entire watershed) or distributed (for selected subbasins or hydrologic response units (HRUs)) way. In addition, the parameters can be modified by replacement, by addition of an absolute change or by a multiplication of a relative change. In addition to weight assignments for output variables that can be made in multi-objective calibrations (e.g., 50 percent streamflow, 30 percent sediment, 20 percent nutrients), the user can specify a particular objective function that is minimized. The objective function is an indicator of the deviation between a measured and a simulated series (Van Griensven and Bauwens, 2003). An approach often selected as an objective function is the sum of squares of residuals method:

$$SSQ = (1/n) \sum_{i=1,n}^{n} (Q_{i,obs} - Q_{i,sim})^2 \qquad (1)$$

where

SSQ = the sum of squares of the residuals
n = the number of pairs of measured and simulated variables
$Q_{i,obs}$ = observed variable at a daily time scale
$Q_{i,sim}$ = simulated variable at a daily time scale

Equation (1) represents the classical mean square error method that aims at matching a simulated time series to a measured series.

Erosion and sediment yield are estimated for each HRU in SWAT using the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), an enhancement of the USLE (Borah et al., 2006). Sediment is routed through the stream channel considering deposition and degradation processes and using a simplified equation based on stream power. SWAT comprehensively models transfers and internal cycling of the major forms of nitrogen and phosphorus. The model monitors two pools of inorganic and three pools of organic forms of nitrogen. SWAT also monitors three pools of inorganic and three pools of organic forms of phosphorus. SWAT incorporates instream nutrient dynamics using kinetic routines from the instream water quality model referred to as QUAL2E (Brown and Barnwell, 1987). Other in-stream variables that are simulated include temperature, dissolved oxygen, bacteria, and pesticides.

Model documentation is well formulated in SWAT, with considerable detail that is provided regarding model structure, algorithms, data input, and viewing of test results. SWAT documentation can be accessed through the theoretical documentation and user's manuals (Neitsch et al., 2002).

Watershed Delineation within AVSWAT 2003

Elevation, land use, and soil characteristics were obtained from GIS data layers for the Blackfoot Watershed. The elevation layer was developed from a 30 m DEM obtained from the Shuttle Radar Topography Mission (Rabus et al., 2003), and the soils layer was obtained from available STATSGO data. The land use layer was obtained from the 1992 USGS National Land Cover Database and was modified by including data from Landsat satellite imagery and historic county water resource surveys to better describe the presence of irrigated pasture on the watershed.

For this investigation, 65 subbasins were delineated in the Blackfoot to account for climatic variations based on the spatial distribution of precipitation and temperature gages within the watershed and to account for hydrologic differences among impaired subwatersheds within the watershed. Five reservoir files were also created to consider the effects of storage and release of water from the larger dams within the watershed. The number of HRUs in the delineation of the respective watersheds was constrained by a threshold based on a land use and soil type covering an area of at least 10 percent and 10 percent, respectively, within any given subbasin. At this threshold level, a total of 633 HRUs were delineated within the Blackfoot. The original delineation of the watershed considered five land cover types that included forest, irrigated pasture with cattle grazing, range-grass, range-brush, and wetlands. This delineation was later modified to include four additional land cover/management types that consisted of urban development, residential development, forest harvest, and forest roads. Cattle grazing within the watershed was also expanded to include seasonal variations among the pasture, range, and forest cover types within a given subbasin.

Default values of the runoff curve number in SWAT were assigned to the various land cover types that were originally delineated in the Blackfoot project. Curve numbers were estimated for the urban development, residential development, forest harvest, and forest roads based on information available from published data by SCS (1986) and our understanding of existing field conditions on the watershed.

Table D-1 presents a listing of the respective land cover types, percent of watershed areas, representative curve number values, and USLE C factors for each land cover type delineated in the Blackfoot project. USLE C factor values shown in **Table D-1** represent values that yield average annual erosion rates that are similar to those reported in the literature for various land cover conditions present in Montana.

Table D-1. A Listing of the Representative Land Cover Types, Percent of Watershed Areas, Representative Curve Numbers, and USLE C Factors Delineated In the Blackfoot Project

Land Use/Management	Percent of Watershed Area	Representative Curve Number	USLE C Factor
Pasture	3.5	49	0.018
Range brush	6.6	41	0.04
Range grass	15.5	49	0.045
Wetlands	0.2	46	0.0085
Forest	71	35	0.004
Forest harvest	0.7	39	0.01
Forest roads	0.2	80	0.85
Urban	0.3	72	0.1
Residential	2	49	0.045

Urban and Residential Septic Systems

HRUs within SWAT were modified to estimate the impact of on-site septic systems within the Blackfoot Watershed. Urban and residential septic systems were represented on 16 of the 65 subbasins based on estimates of population density within the watershed. Nitrogen and phosphorus were applied at equivalent rates of 60 and 10 mg per liter, respectively. Septic discharge was assumed to be 165 liters per person per day times an average household occupancy of 2.5 persons. The resultant N and P application rates were therefore 2.48 and 0.41 kg per ha per day, respectively. These nutrients were input into SWAT as fertilizer beneath the land surface on a daily basis throughout the year.

Forest Roads

HRUs within SWAT were also modified to estimate the impact of unpaved forest roads within the watershed. These roads were represented on 8 of the 65 subbasins, and were assumed to have a slope steepness of 7 percent and a slope length of 5 m.

Miscellaneous Land Cover Types

Fertilizer 28-47-7 was assumed to be applied each year on April 15th at a rate of 282 Kg/ha on the pasture land cover type. If a given subbasin within the delineated project contained pasture as one of the cover types, it was assumed that livestock would be rotated among pasture, range grass, and forest cover types within that subbasin according the schedule presented in **Table D-2**. Livestock density on pasture, range grass, and forest lands was assumed to be 1.2, 0.35, and 0.067 animals per ha, respectively.

Table D-2. Yearly Simulated Rates of Total Nitrogen and Total Phosphorus from Fertilizer or Livestock Sources

Source	Land Cover	Time of Application	Annual Total N (Kg/ha)	Annual Total P (Kg/ha)
Fertilizer	Pasture	April 15th	79	56
Livestock	Pasture	Daily: Nov 1st to April 14th	17.2	4.7
Livestock	Range grass	Daily: April 15th to June 14th	1.6	0.45
Livestock	Forest	Daily: June 15th to Oct. 31st	0.78	0.22
Fertilizer*	Residential	Daily	905	150
Fertilizer*	Urban	Daily	905	150

*applied fertilizer used to mimic on site septic systems

Hydrologic Calibration and Validation

Based on available climatic and streamflow data within the watershed, model parameters in SWAT were calibrated for a period of record from 2002 to 2004 at four streamgaging locations. To account for spatial variability in topographic, soil, and land use factors among subwatersheds within the Blackfoot, parameters governing streamflow response in SWAT were calibrated in a distributed fashion using the automated calibration procedure, where observed and simulated outputs were compared at the same outlet points on the watershed. Therefore, with the completion of the optimization run, a set of calibrated parameters was computed for the Blackfoot River above Nevada Creek, Nevada Creek below the reservoir, the North Fork of the Blackfoot River, and the Blackfoot River near Bonner. With a decision that was made sometime following the streamflow autocalibration, two additional gaging stations were added as calibration points within the watershed. These two additional calibration points included the Nevada Creek above the reservoir and Clearwater Creek subwatersheds within the Blackfoot. Since streamflow data were not available for Clearwater Creek during the 2002 to 2004 period, the average annual ratio of streamflow for Clearwater Creek to Blackfoot River at Bonner based on the 1975 to 1992 available period of record for these two gages was used to estimate parameter values for the Clearwater subwatershed. Manual adjustments were then implemented at the six locations to fine tune the autocalibration. Available streamflow data at Nevada Creek above the reservoir, the North Fork of the Blackfoot River, and the Blackfoot River near Bonner from 1998 to 2001 were used for model validation. A description of parameters calibrated in the model is as follows.

Description of Calibration Parameters

For this investigation, fourteen parameters that govern hydrologic processes in SWAT were selected for calibration on the Blackfoot Watershed. Although the runoff curve number (CN2) could have also been calibrated, default values input during project delineation were assumed to be valid for model simulations. This assumption in turn facilitated the selection of appropriate curve number values for proposed changes in land management and cover associated with various simulation scenarios. The 14 hydrologic model parameters were grouped into three categories (**Table D-3**), which were considered to predominantly govern surface, subsurface, and basin response.

Following calibration of the hydrologic response of the model, 15 parameters governing sediment and nutrient response on the Bitterroot Watershed were calibrated. These 15 parameters are presented in **Table D-3**. The following is a brief description of parameters governing hydrologic, sediment and nutrient response in SWAT.

Parameters Governing Surface Response

Calibration parameters governing the surface water response in SWAT include the soil evaporation compensation factor and the available soil water capacity. The soil evaporation compensation factor (ESCO) adjusts the depth distribution for evaporation from the soil to account for the effect of capillary action, crusting, and cracks. The available soil water capacity (SOL_AWC) is the volume of water that is available to plants if the soil was at field capacity. It is estimated by determining the amount of water released between in situ field capacity and the permanent wilting point.

Parameters Governing Subsurface Response

Six calibration parameters govern the subsurface water response in SWAT. One of these parameters is referred to as the ground water "revap" coefficient (GW_REVAP), which controls the amount of water that will move from the shallow aquifer to the root zone as a result of soil moisture depletion and the amount of direct ground water uptake from deep-rooted trees and shrubs. Another parameter that governs the subsurface response is the threshold depth of water in the shallow aquifer for "revap" to occur (REVAPMN). Movement of water from the shallow aquifer to the root zone or to plants is allowed only if the depth of water in the shallow aquifer is equal to or greater than the minimum "revap." A third parameter is the threshold depth of water in the shallow aquifer required for return flow to occur to the stream (GWQMN). Two other parameters that govern watershed response include the baseflow alpha factor and ground water delay. The baseflow alpha factor (ALPHA_BF), or recession constant, characterizes the ground water recession curve. This factor approaches one for flat recessions and approaches zero for steep recessions. The ground water delay (GW_DELAY) is the time required for water leaving the bottom of the root zone to reach the shallow aquifer. A sixth factor is the deep aquifer percolation fraction which governs the fraction of percolation from the root zone to the deep aquifer (RCHRG_DP).

Parameters Governing Basin Response

Seven parameters that govern basin response in SWAT were calibrated in this study. Two of these parameters included channel hydraulic conductivity (CH_K2) that governs the movement of water from the streambed to the subsurface and the surface runoff lag time (SURLAG) that accounts for the storage of runoff in the model for a given subbasin. Five other basin parameters govern snowfall and snowmelt in SWAT. One parameter is the snowfall temperature (SFTMP) which is the mean air temperature at which precipitation is equally likely to be rain as snow or freezing rain. A second parameter is the snowmelt base temperature (SMTMP) that defines the snow pack temperature above which snowmelt will occur. SMFMX and SMFMN are melt factors for snow on June 21 and December 21, respectively, in the Northern Hemisphere that allow the rate of snowmelt to vary through the year as a function of snow pack density. A fifth parameter is the snow pack temperature lag factor (TIMP) that controls the impact of the current day's air temperature on the snow pack temperature.

Parameters Governing Sediment Response

Four parameters in SWAT must be calibrated to simulate processes of erosion and sedimentation in the model. One of these parameters is the channel erodibility factor (CH_EROD) which is conceptually similar to the soil erodibility factor in the universal soil loss equation. A second parameter is the channel cover factor (CH_COV) which is defined as the ratio of degradation from a specified vegetative cover to the corresponding degradation from a channel with no vegetative cover. The third and fourth sediment parameters that must be calibrated in SWAT are the coefficient and exponent parameters that are used to calculate the maximum amount of sediment that can be reentrained during channel sediment routing. These two parameters are referred to respectively as SPCON and SPEXP.

Parameters Governing Nutrient Response

Several parameters govern the movement and transformation of various constituents of nitrogen and phosphorus in SWAT. Five parameters govern nitrogen fate and transport on the landscape. One of these parameters in SWAT is referred to as the nitrogen uptake distribution parameter (N_UPDIS) which controls the amount of nitrogen removed from the different soil layers by the plant. A second parameter is the rate factor for humus mineralization of active organic nitrogen (CMN). A third parameter is referred to as the nitrogen percolation coefficient (NPERCO). This parameter controls the amount of mineral N removed from the surface layer in runoff relative to the amount removed via percolation. The fourth and fifth parameters are SOL_NO3 and SOL_ORGN which represent the initial nitrate and organic N concentrations in the respective soil layers.

Six parameters control phosphorus rate and transport on the landscape. One of these parameters governing phosphorus response in the model is referred to as the phosphorus percolation coefficient (PPERCO). Like NPERCO for nitrogen, PPERCO controls the ratio of the amount of soluble P removed from the surface layer in runoff relative to the amount of soluble P removed via percolation. A second parameter is the phosphorus soil partitioning coefficient (PHOSKD), which represents the ratio of phosphorus attached to sediment to phosphorus dissolved in soil water. A third parameter describes the phosphorus uptake distribution (P_UPDIS) which governs the plant uptake of phosphorus from the different soil horizons in the same way that N_UPDIS controls nitrogen uptake. Yet a fourth parameter is the phosphorus sorption coefficient (PSP). This parameter represents the fraction of mineral phosphorus remaining in the labile pool after initial rapid sorption to the soil. The fifth and sixth parameters are SOL_LABP and SOL_ORGP which represent the initial soluble P and organic P concentrations in the respective soil layers.

Table D-3. A Listing of Parameters, Their Description, and Units That Were Calibrated In SWAT

Parameter	Description	Units
Parameters governing surface water response		
ESCO	soil evaporation compensation factor	none
SOL_AWC	available soil water capacity	mm/mm
Parameters governing subsurface water response		
ESCO	soil evaporation compensation factor	none
SOL_AWC	available soil water capacity	mm/mm
Parameters governing subsurface water response		
GW_REVAP	ground water "revap" coefficient	none
REVAPMN	threshold depth of water in the shallow aquifer for "revap to occur"	mm
GWQMN	threshold depth of water in the shallow aquifer required for return flow to occur	mm
GW_DELAY	ground water delay	days
ALPHA_BF	baseflow alpha factor, or recession constant	days
RCHRG_DP	deep aquifer percolation fraction	fraction
Parameters governing basin response		
SFTMP	snowfall temperature	degrees C
SMTMP	snowmelt temperature	degrees C
SMFMX	melt factor for snow on June 21	mm/deg C day
SMFMN	melt factor for snow on December 21	mm/deg C day
TIMP	snow pack temperature lag factor	none
SURLAG	surface runoff lag time	days
Parameters governing sediment response		
CH_EROD	channel erodibility factor	none
CH_COV	channel cover factor	cm/hour-Pa
SPCON	coefficient for sediment reentrainment function	none
SPEXP	exponent for sediment reentrainment function	none
Parameters governing nutrient response		
N_UPDIS	nitrogen uptake distribution factor	none
CMN	humus mineralization of active organic nitrogen factor	none
NPERCO	nitrogen percolation coefficient	10 m**3/Mg
SOL_NO3	initial nitrate concentration in soil layer	mg/kg
SOL_ORGN	initial organic nitrogen concentration in soil layer	mg/kg
PPERCO	phosphorus percolation coefficient	10 m**3/Mg
PHOSKD	phosphorus soil partitioning coefficient	none
P_UPDIS	phosphorus uptake distribution factor	none
PSP	phosphorus sorption coefficient	none
SOL_LABP	initial soluble phosphorus concentration in soil layer	mg/kg
SOL_ORGP	initial organic phosphorus concentration in soil layer	mg/kg

Evaluation Criteria

Four evaluation criteria were used to assess monthly and daily streamflow simulated by SWAT. The first evaluation criterion used was the percent bias (PBIAS), which is a measure of the average tendency of the simulated flows to be larger or smaller than their observed values. The optimal PBIAS value is 0.0; a positive value indicates a model bias toward underestimation, whereas a negative value indicates a bias toward overestimation (Gupta et al., 1999). PBIAS may be expressed as

$$PBIAS = \sum_{k=1,n} (Qk\ obs - Qk\ sim)(100) / \sum_{k=1,n} (Qk\ obs) \quad (2)$$

where

PBIAS = deviation of streamflow discharge, expressed as a percent
$Q_{k\ obs}$ = observed streamflow in $m^3\ s^{-1}$ (cms)
$Q_{k\ sim}$ = simulated streamflow (cms)

Donigian et al. (1983) considered HSPF model performance “very good” if the absolute percent error is <10 percent, “good” if the error is between 10 percent and <15 percent, and “fair” if the error is between 15 percent and <25 percent for calibration and validation. Measurement errors associated with streamflow as recommended by Harmel et al. (2006) follow the same standard. This standard was therefore adopted for the PBIAS evaluation criterion used in this study, with PBIAS values >25 percent considered as unsatisfactory.

The second evaluation criterion was the model coefficient of efficiency (NSE; Nash and Sutcliffe, 1970), which Sevat and Dezetter (1991) found to be the best objective function for reflecting the overall fit of a hydrograph. NSE expresses the fraction of the measured streamflow variance that is reproduced by the model.

$$NSE = 1 - \left[\sum_{k=1,n}^{n} (Qk\ obs - Qk\ sim)2 / \sum_{k=1,n}^{n} (Qk\ obs - Qmean)2\right] \quad (3)$$

where

NSE = Nash Sutcliffe coefficient of efficiency
Q_{mean} = mean observed streamflow during the evaluation period (cms)

NSE values were computed for both monthly and daily streamflow. Simulation results were considered to be good for values of NSE >0.75, while for values of NSE between 0.75 and 0.36, the simulation results are considered to be satisfactory. (Motovilov et al., 1999). For this study NSE values <0.36 were considered to be unsatisfactory.

The third evaluation criterion compared simulated daily and monthly hydrographs to observed values. At the daily time scale, particular attention was given to the timing and magnitude of peak flows and the shape of the recession curves. The fourth criterion compared average monthly measured versus simulated streamflow for the calibration period.

Results of Streamflow Calibration

Average annual values of precipitation as well as measured and simulated streamflow for five of the watershed measurement points are presented in **Table D-4**. Especially noteworthy in the table is the differences in average annual precipitation and discharge for the Nevada Creek subwatershed as compared to either the Blackfoot River above Nevada Creek or the North Fork of the Blackfoot River subwatersheds. For the calibration period for example, the Nevada Creek below the reservoir subwatershed average annual precipitation of 445 mm is about half of the 848 mm measured for the Blackfoot River above Nevada Creek subwatershed. For this time series the measured average annual discharge for Nevada Creek below the reservoir was 64 mm, or about 20 percent of the measured value of 316 mm for the Blackfoot River above Nevada Creek.

Table D-4. Drainage Area, Average Annual Precipitation, and Measured Versus Simulated Average Annual Discharge for the Blackfoot Streamgaging Locations

Measurement Point and Simulation Type	Drainage Area (Km^2)	Average Annual Precipitation (mm)	Measured Average Annual Discharge (mm)	Simulated Average Annual Discharge (mm)
Blackfoot abv Nevada-c*	1294	848	316	318
Nevada Cr abv res-c	310	471	70	67
Nevada Cr abv res v*	310	486	80	66
Nevada Cr bel res-c	885	445	64	66
North Fk Blackfoot-c	824	941	409	406
North Fk Blackfoot-v	824	919	377	333
Blackfoot nr Bonner-c	5958	819	203	204
Blackfoot nr Bonner-v	5958	809	194	192

c* = calibration v* = validation

Percent bias and the Nash Sutcliffe (1970) coefficient of efficiency values are presented in **Table D-5** for the calibration and validation periods on the Blackfoot Watershed. A comparison of measured versus simulated daily hydrographs shows good agreement for the Blackfoot River above Nevada Creek, the North Fork of the Blackfoot River, and the Blackfoot River at Bonner subwatersheds (**Figures D.1-D.3**). Based on the calibration period from 2002 to 2004, daily NSE values were 0.68, 0.81, and 0.77 for these three subwatersheds, respectively. A comparison of measured versus simulated daily hydrographs was considered poor for the calibration period for Nevada Creek above the reservoir (NSE = 0.08) and Nevada Creek below the reservoir (-0.26) (**Figures D-4 and D-5**), and adequate for the validation period for Nevada Creek above the reservoir (0.46). The difficulties encountered in calibrating the Nevada Creek subwatershed were attributed in part to an inadequate precipitation signal based on the available climatological stations on or near the watershed and the fair to poor measured streamflow records collected by the USGS which are due to the numerous irrigation diversions in the subwatershed.

Table D-5. Percent Bias and Nash Sutcliffe Coefficient of Efficiency Statistics for Streamflow during the Calibration (2002-2004) and Validation (1998-2001) Periods on the Blackfoot Watershed

Measurement Point	Time Series	Percent Bias	Monthly NSE	Daily NSE
BFT abv Nevada	Calibration	-5.9%	0.78	0.68
Nevada Cr. abv res	Calibration	6.9%	0.27	0.08
Nevada Cr. abv res	Validation	19.30%	0.6	0.46
Nevada Cr. bel res	Calibration	-2.70%	-0.17	-0.26
North Fk BFT	Calibration	-1.60%	0.91	0.81
North Fk BFT	Validation	13.90%	0.9	0.82
BFT nr Bonner	Calibration	-10.00%	0.81	0.77
BFT nr Bonner	Validation	-0.70%	0.84	0.81

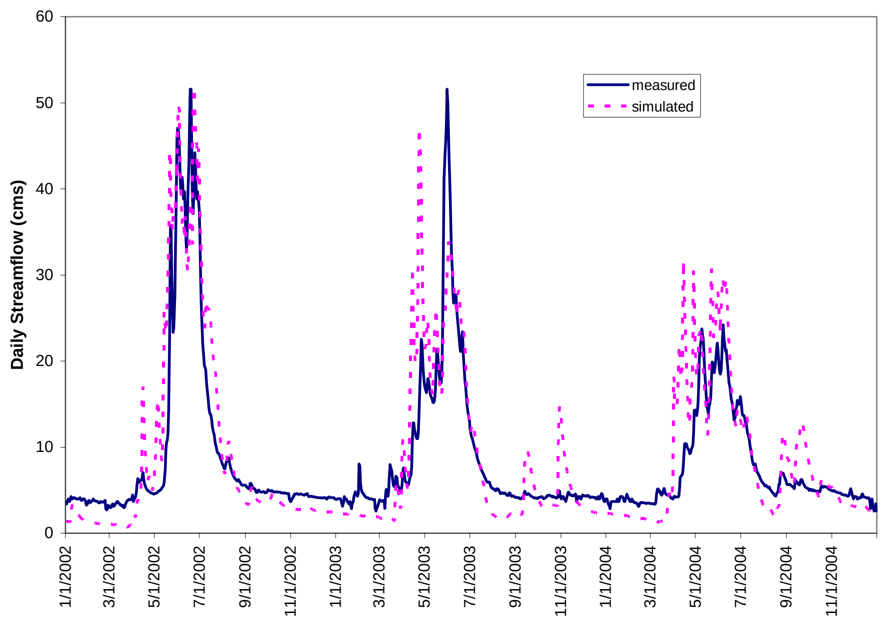

Figure D-1. Comparison of Measured Versus Simulated Daily Discharge for the Blackfoot River above Nevada Creek during The 2002 To 2004 Calibration Period

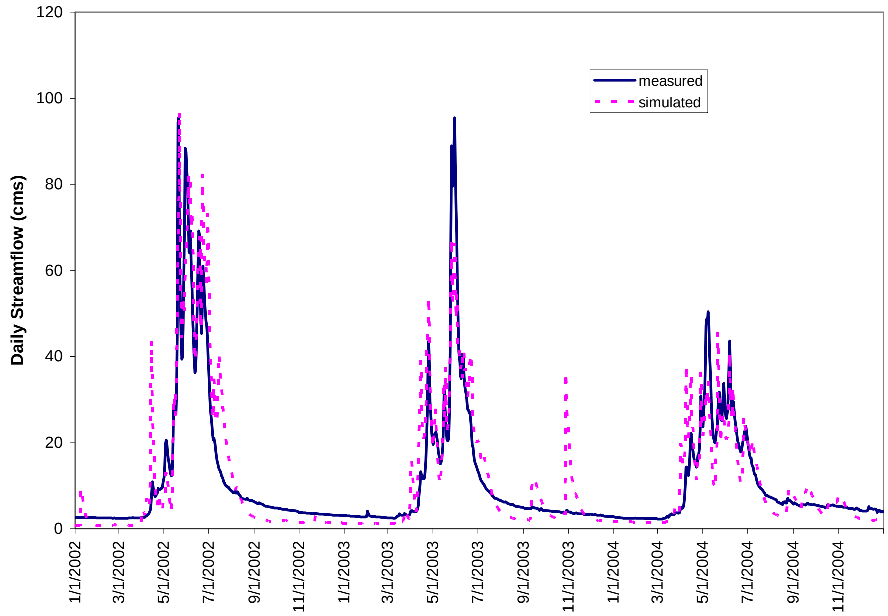

Figure D-2. Comparison of Measured Versus Simulated Daily Discharge for the North Fork of the Blackfoot River during The 2002 To 2004 Calibration Period

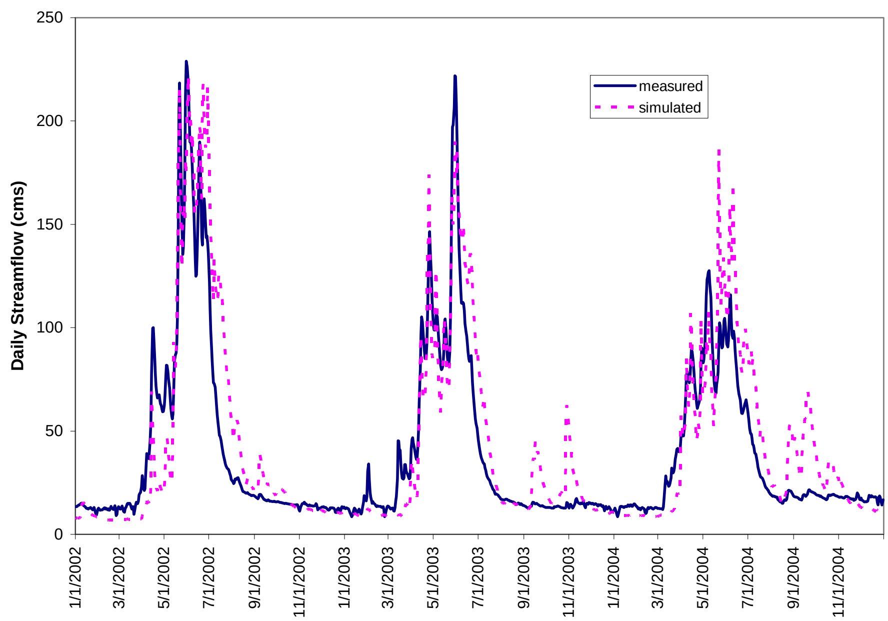

Figure D-3. Comparison of Measured Versus Simulated Daily Discharge for the Blackfoot River at Bonner during The 2002 To 2004 Calibration Period

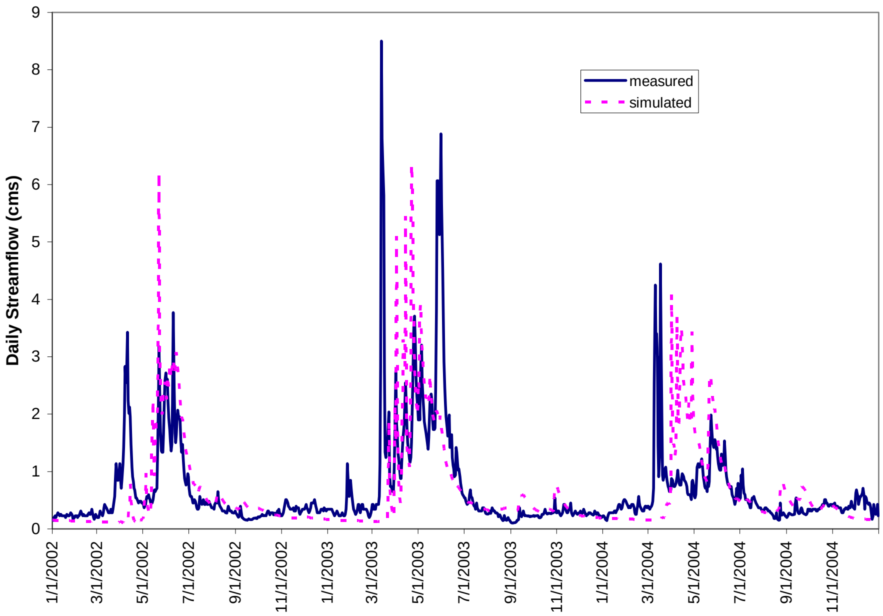

Figure D-4. Comparison of Measured Versus Simulated Daily Discharge for Nevada Creek above the Reservoir during The 2002 To 2004 Calibration Period

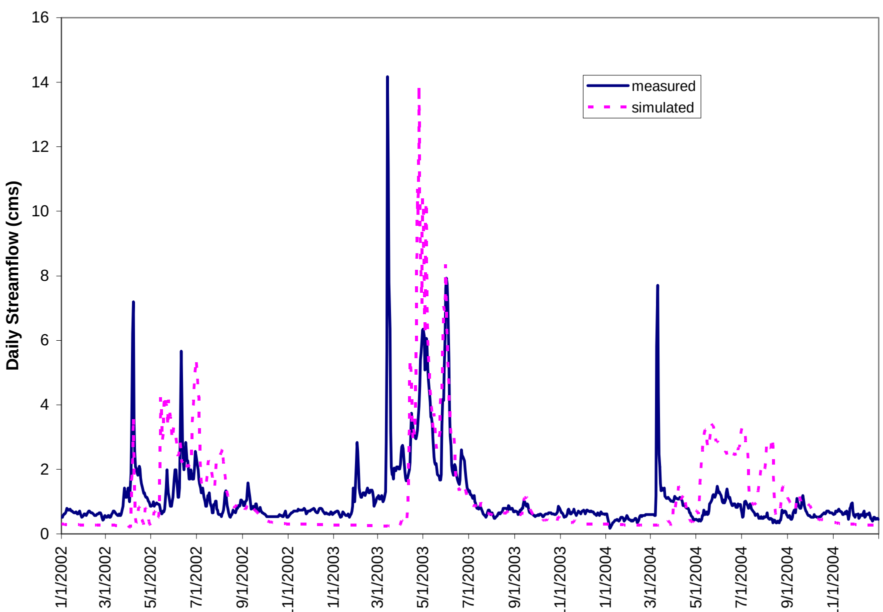

Figure D-5. Comparison of Measured Versus Simulated Daily Discharge for Nevada Creek below the Reservoir during The 2002 To 2004 Calibration Period

With the exception of the Nevada Creek subwatershed (**Figure D-6**), very good agreement was obtained in the comparison of measured versus simulated monthly hydrographs as illustrated in **Figures D-7 and D-8** for the North Fork of the Blackfoot River and the Blackfoot River at Bonner, respectively. Examination of the average monthly measured versus simulated hydrographs shows that SWAT tended to somewhat underestimate flows during the winter and late fall months (**Figures D-9 through D-11**). A suitable explanation could not be found to account for SWAT's tendency to substantially underestimate flows during the month of March for Nevada Creek above the reservoir.

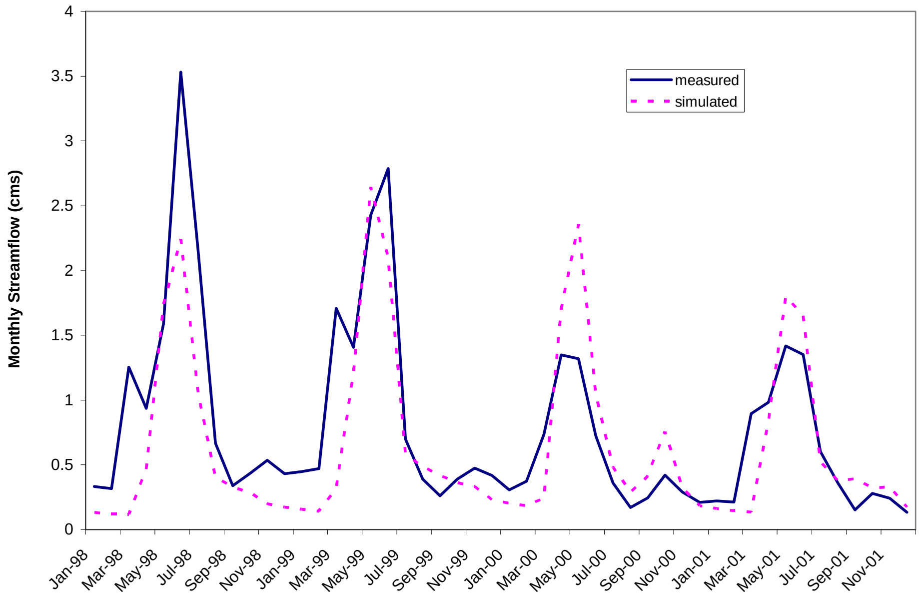

Figure D-6. Comparison of Measured Versus Simulated Monthly Discharge for Nevada Creek above the Reservoir during the 1998 To 2001 Validation Period

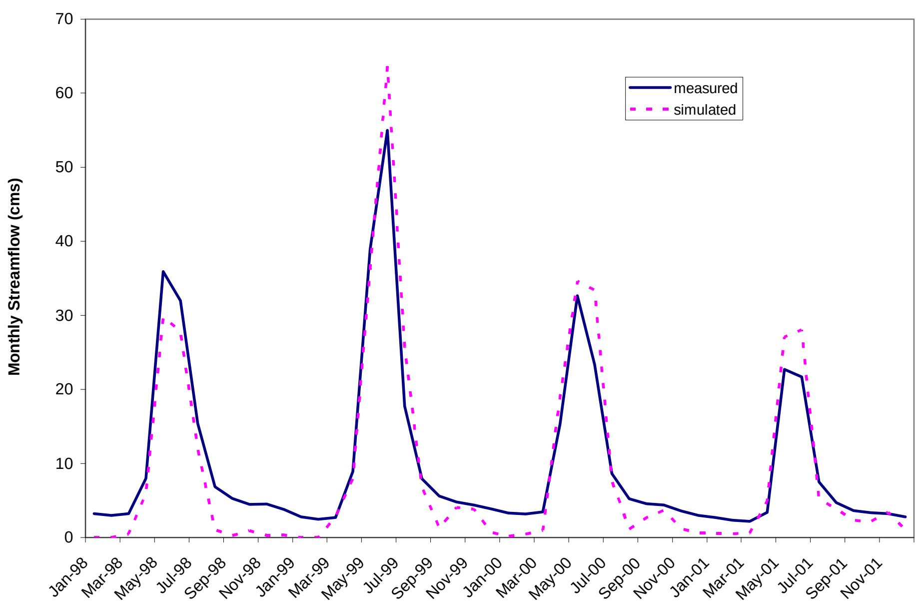

Figure D-7. Comparison of Measured Versus Simulated Monthly Discharge for the North Fork of the Blackfoot River during the 1998 To 2001 Validation Period

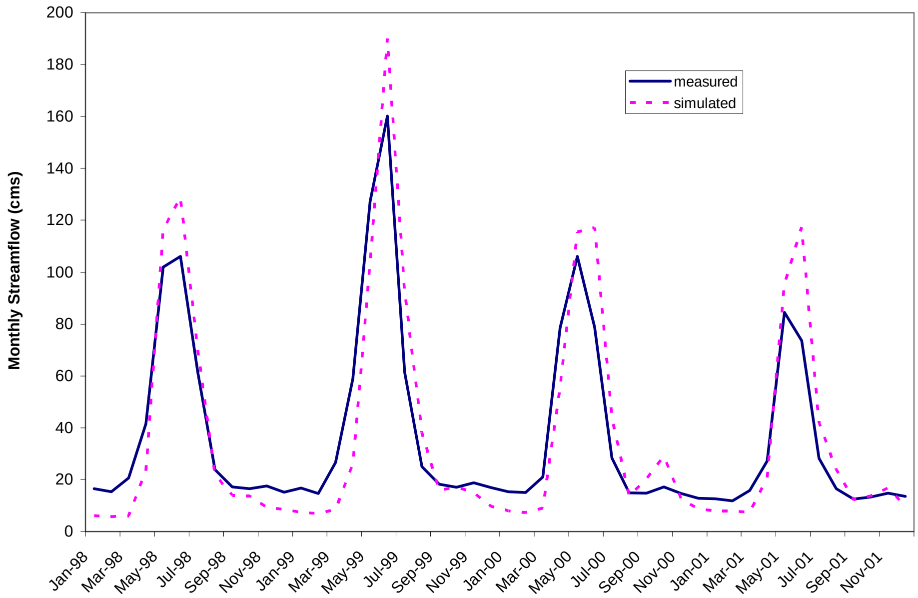

Figure D-8. Comparison of Measured Versus Simulated Monthly Discharge for the Blackfoot River at Bonner during the 1998 To 2001 Validation Period

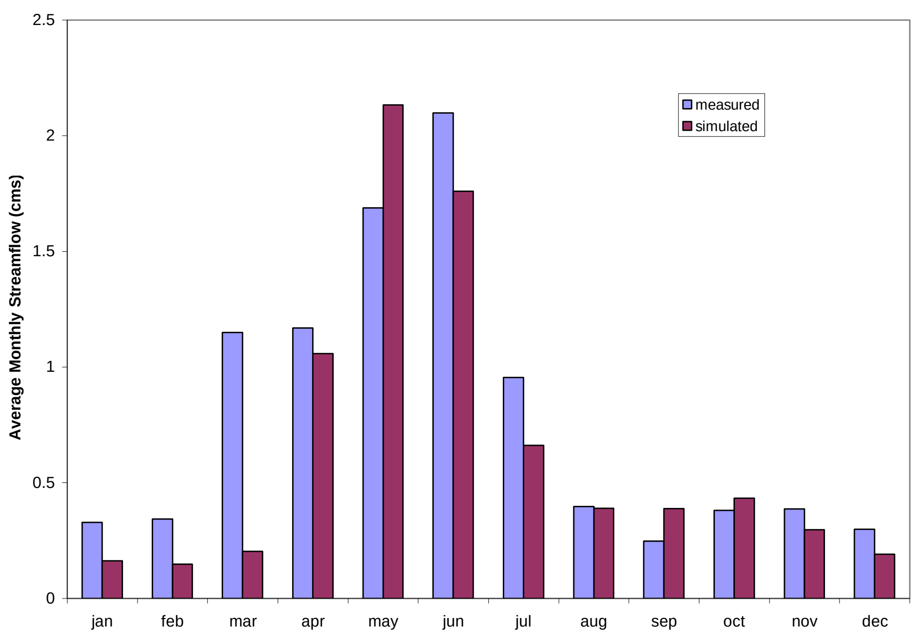

Figure D-9. Comparison of Measured Versus Simulated Average Monthly Discharge for Nevada Creek above the Reservoir during the 1998 To 2001 Validation Period

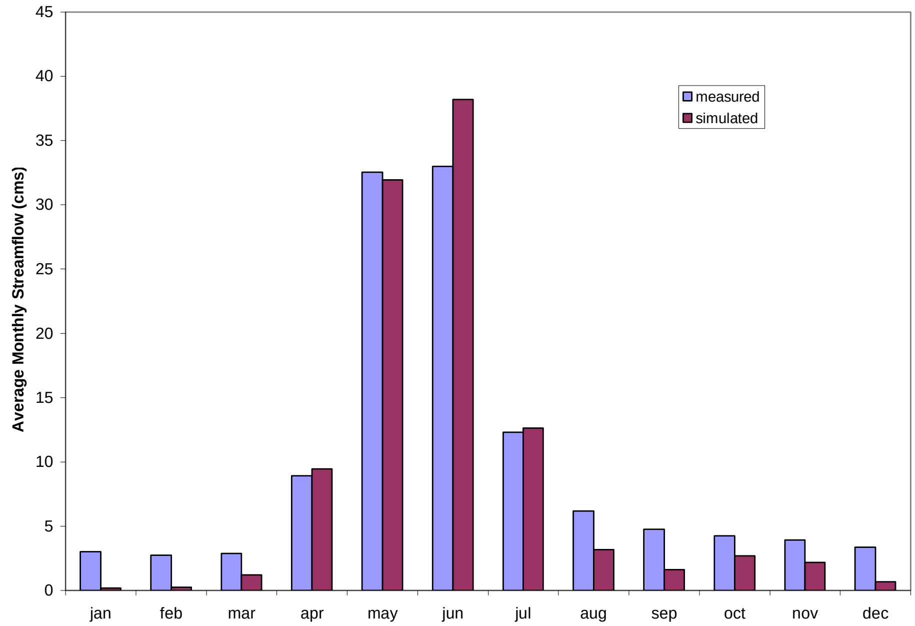

Figure D-10. Comparison of Measured Versus Simulated Average Monthly Discharge for the North Fork of the Blackfoot River during the 1998 To 2001 Validation Period

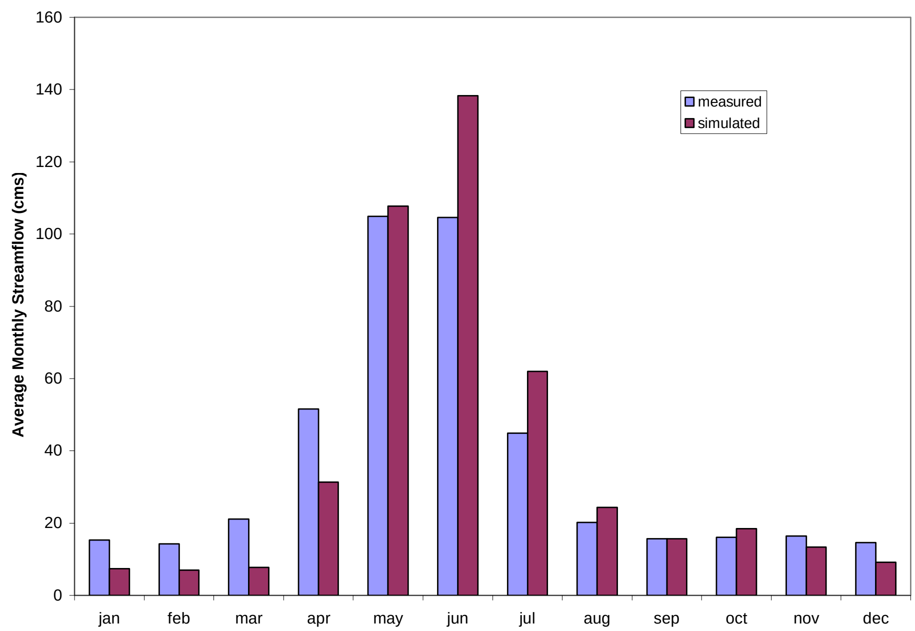

Figure D-11. Comparison of Measured Versus Simulated Average Monthly Discharge for the Blackfoot River at Bonner during the 1998 To 2001 Validation Period

Cursory testing with SWAT revealed that improvements in streamflow on the Blackfoot Watershed could be achieved in at least two ways. First of all, a single set of parameters was used to describe snow accumulation and melt processes across the basin. The utilization of regional sets of calibration parameters to account for these processes in the model would better represent spatial and temporal variations that take place across the watershed. Second, the hydrologic calibration did not include a consumptive use term to account for various losses associated with irrigation of pasture lands on the watershed. Recalibration of the model by adjusting the deep aquifer recharge parameter and including monthly consumptive use losses during the summer and early fall months would result in better matches between measured and simulated streamflow for the winter and summer months.

Calibration of Water Quality Parameters

Very limited data were available to calibrate sediment, total nitrogen, and total phosphorus for the Blackfoot Watershed. For these three water quality constituents, only 5 to 16 measured instantaneous values were used for calibration at any given streamgaging location. Sites selected for model calibration included the Blackfoot River above Nevada Creek, Nevada Creek above the reservoir, Nevada Creek below the reservoir, the North Fork of the Blackfoot River, and the Blackfoot River near Bonner locations. Model calibrations were performed by comparing graphical results of measured versus simulated constituent concentrations. A comparison of average measured versus simulated daily sediment, total nitrogen, and total phosphorus concentration for the calibration period at the five measurements points in the watershed is presented in **Table D-6**.

Table D-6. Comparison of Average Measured Versus Simulated Daily Sediment, Total Nitrogen, and Total Phosphors Concentration for the Calibration Period (2002-2004) At the Five Measurements Points on the Blackfoot Watershed

USGS Gage Location	Constituent	Number of Measured Points	Avg. Measured Concentration (mg/L)	Number of Simulated Points	Avg. Conc. On day of Measurement (mg/L)	Number of Simulated Points	Avg. Simulated Conc. For Calibration Period
Bk abv Nevada	Sediment	14	28.6	14	41.3	1096	17.6
Bk abv Nevada	Total N	6	0.1	6	0.152	1096	0.104
Bk abv Nevada	Total P	14	0.0253	14	0.0136	1096	0.009
Nevada abv Res	Sediment	10	11.6	10	12.6	1096	6.2
Nevada abv Res	Total N	6	0.463	6	0.13	1096	0.467
Nevada abv Res	Total P	10	0.0783	10	0.129	1096	0.512
Nevada bel Res	Sediment	16	45.3	16	7.3	1096	3.4
Nevada bel Res	Total N	6	1.05	6	0.573	1096	0.302
Nevada bel Res	Total P	13	0.21	13	0.688	1096	0.227
North Fk Bk	Sediment	5	3.2	5	55	1096	28.5
North Fk Bk	Total N	5	0.13	5	0.148	1096	0.202

Table D-6. Comparison of Average Measured Versus Simulated Daily Sediment, Total Nitrogen, and Total Phosphors Concentration for the Calibration Period (2002-2004) At the Five Measurements Points on the Blackfoot Watershed

USGS Gage Location	Constituent	Number of Measured Points	Avg. Measured Concentration (mg/L)	Number of Simulated Points	Avg. Conc. On day of Measurement (mg/L)	Number of Simulated Points	Avg. Simulated Conc. For Calibration Period
North Fk Bk	Total P	5	0.0052	5	0.0128	1096	0.0086
Bk near Bonner	Sediment	16	25.5	16	35.7	1096	15.7
Bk near Bonner	Total N	6	0.117	6	0.182	1096	0.132
Bk near Bonner	Total P	13	0.0323	13	0.0265	1096	0.0171

The calibration of sediment loading with SWAT proved to be a very daunting task for the Blackfoot Watershed. Adjusting the four parameters that govern sediment transport and bank erosion within the model did not provide consistent results when compared to measured data for the five calibration points. **Figures D-12 through D-16** illustrate the comparison of measured versus simulated sediment concentration for the five measurements points on the watershed. Results show reasonably good agreement for Nevada Creek above the reservoir, the Blackfoot River above Nevada Creek, and the Blackfoot River at Bonner, but poor agreement for the other two measurement points. Because the sediment calibration consisted of a parameter set with very high values of CH_EROD and CH_COV for the Nevada Creek subwatersheds and very low values for the other three Blackfoot gages, the contribution of sediment from bank erosion sources to total sediment sources was unrealistically low throughout the Blackfoot River reaches. Two improvements could be made in the project to better reflect processes of erosion and sedimentation. First of all, a delineation of the GIS data for the watershed with the option to specify the slope steepness of the various land cover types within a given subbasin would represent a significant improvement in erosion prediction with MULSE across the landscape. Second, the use of regional sets of the SPCON and SPEXP parameters in SWAT instead of a single set for the entire basin would provide the flexibility that is needed to consider spatial variability in sediment transport processes that exist on the watershed.

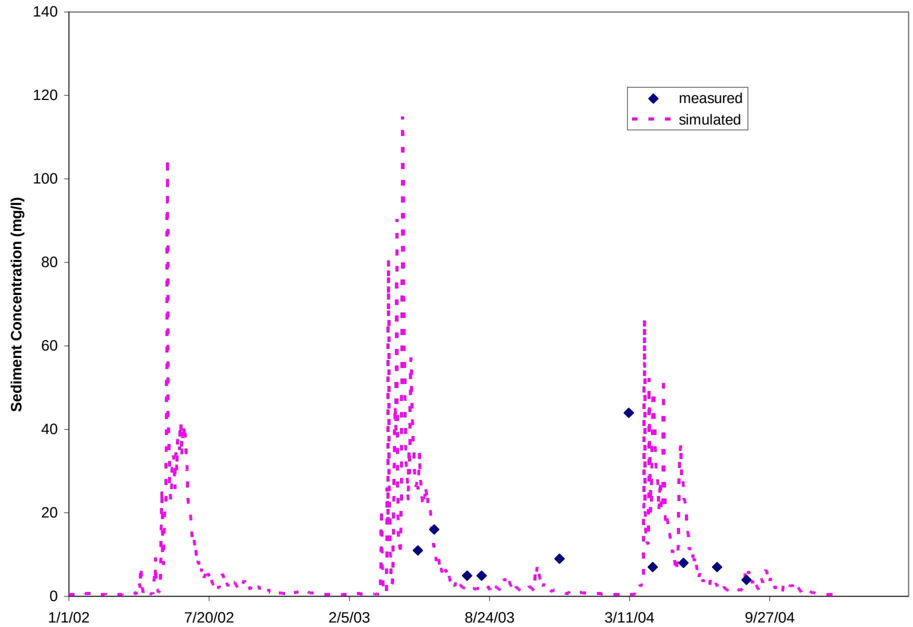

Figure D-12. Comparison of Measured Versus Simulated Sediment Concentration for Nevada Creek above the Reservoir during the 2002 To 2004 Calibration Period

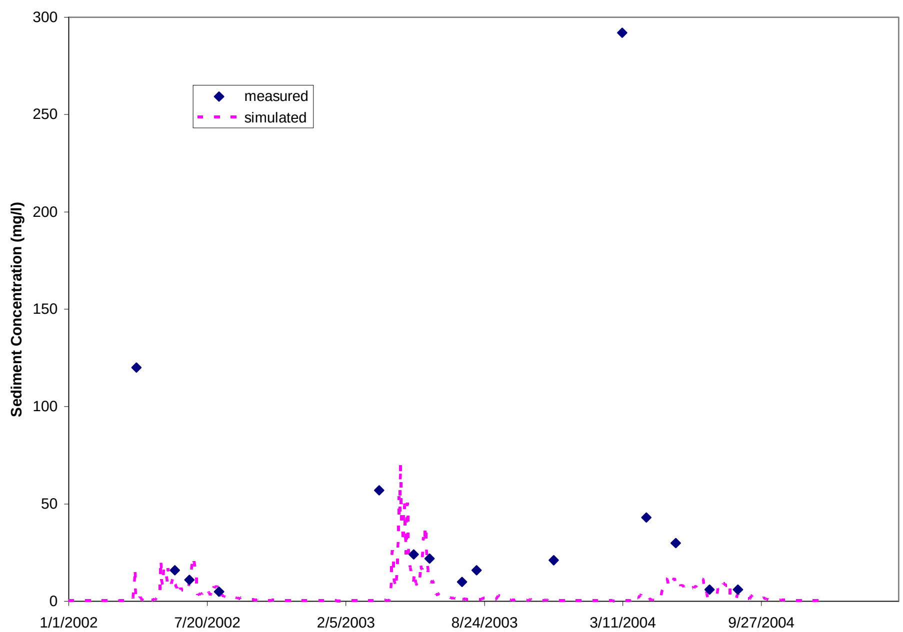

Figure D-13. Comparison of Measured Versus Simulated Sediment Concentration for Nevada Creek below the Reservoir during the 2002 To 2004 Calibration Period

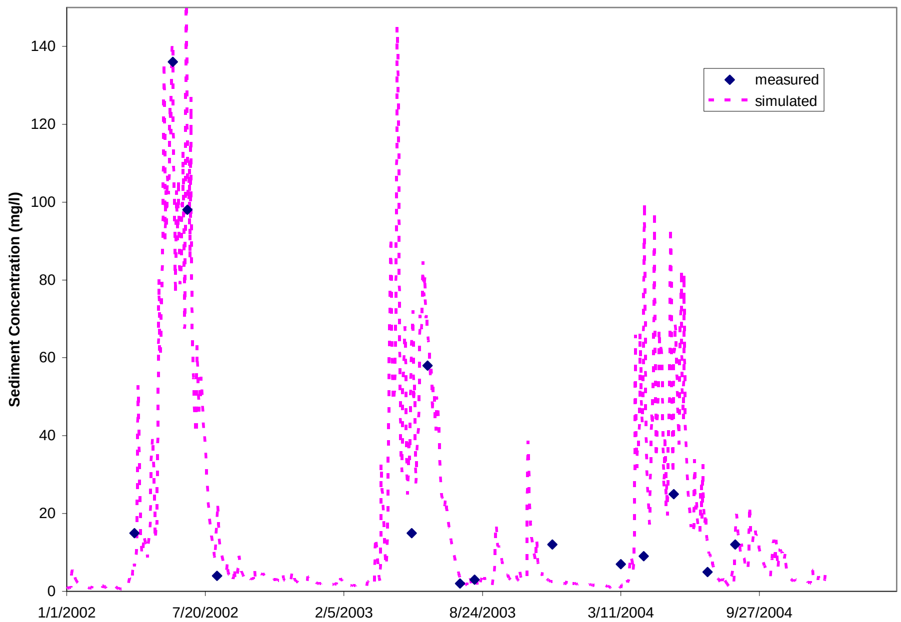

Figure D-14. Comparison of Measured Versus Simulated Sediment Concentration for the Blackfoot River above Nevada Creek during the 2002 To 2004 Calibration Period

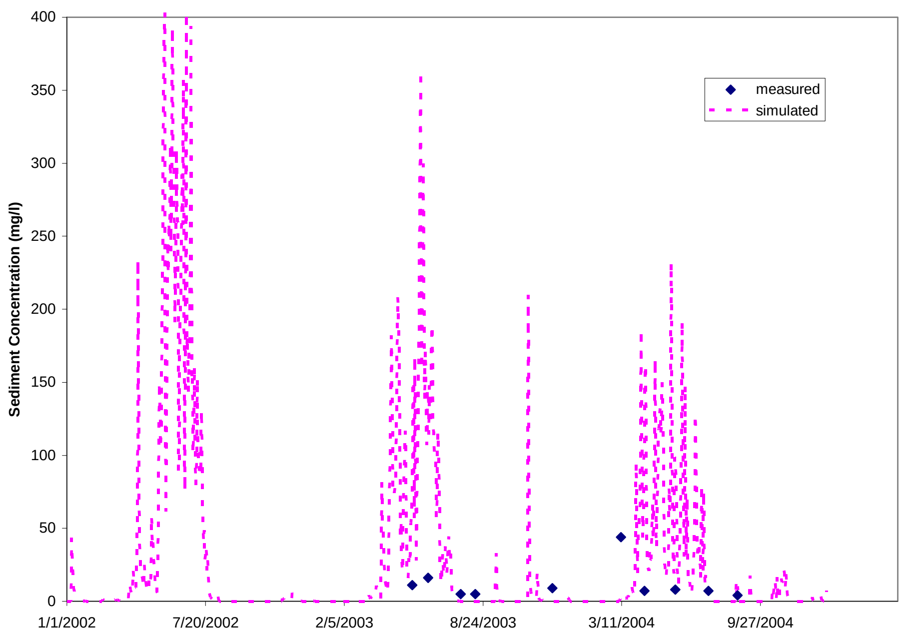

Figure D-15. Comparison of Measured Versus Simulated Sediment Concentration for the North Fork of the Blackfoot River during the 2002 To 2004 Calibration Period

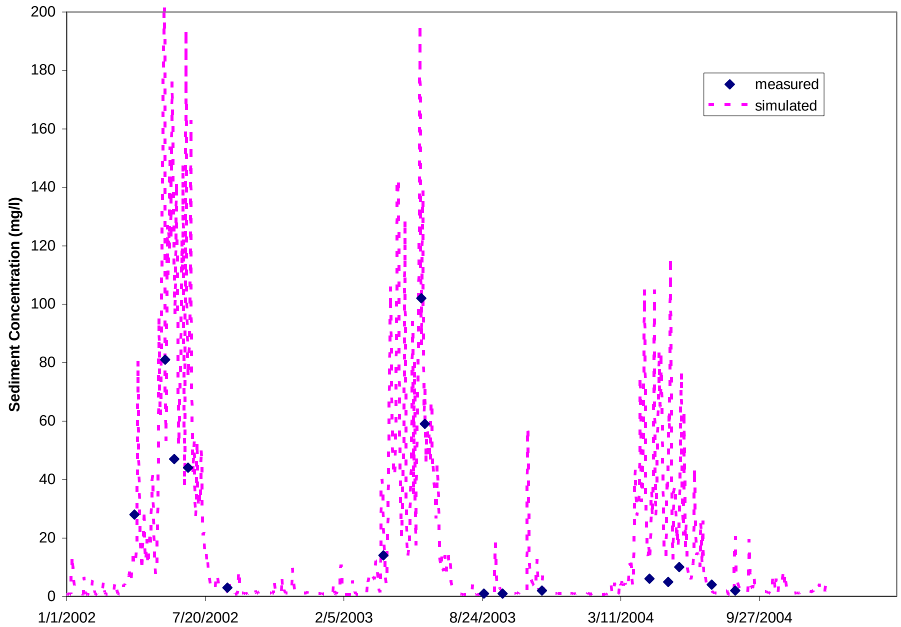

Figure D-16. Comparison of Measured Versus Simulated Sediment Concentration for the Blackfoot River at Bonner during the 2002 To 2004 Calibration Period

Although SWAT simulates the fate and transport of constituent forms of nitrogen and phosphorous, only total N and P were compared with measured data in this study. This is because of the very limited measured data set that was available for model calibration, and because of an apparent model deficiency that exists within SWAT for simulating nitrogen constituents on watersheds like the Blackfoot that primarily consist of snowfed forested areas with steep slopes. Of the available measured nitrogen record collected for the Blackfoot, the data indicate that the organic N and inorganic N generally account for about 80 percent and 20 percent of the total N concentrations, respectively. SWAT simulations showed that these N constituents were more or less the opposite as those from the measured record. In spite of attempts to remedy this problem in the model, no successful solutions were realized. Steps have been taken to request that USDA ARS in Temple, TX, determine a feasible solution to remedy in this deficiency in the model.

Although a number of different approaches were implemented for calibrating nitrogen and phosphorous on the Blackfoot Watershed, none proved to be adequately successful. Results of the model simulations show inconsistencies in simulating total N for the two Nevada Creek subwatersheds (**Table D-6**). This is further illustrated in **Figures D-17 and D-18**. For the other three measurement points, SWAT appeared to do an adequate job simulating total nitrogen (**Figures D-19 through D-21**).

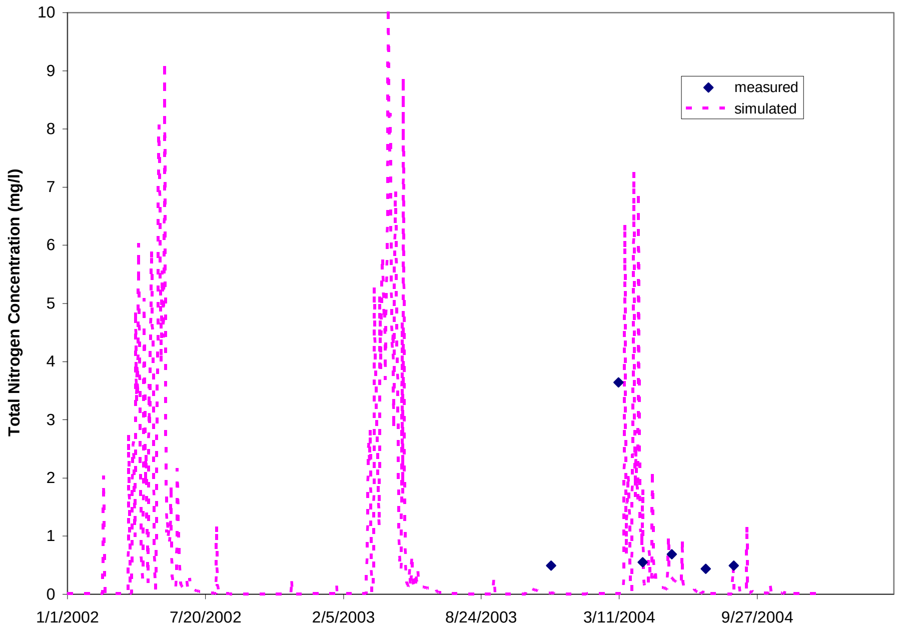

Figure D-17. Comparison of Measured Versus Simulated Total Nitrogen Concentration for Nevada Creek above the Reservoir during the 2002 To 2004 Calibration Period

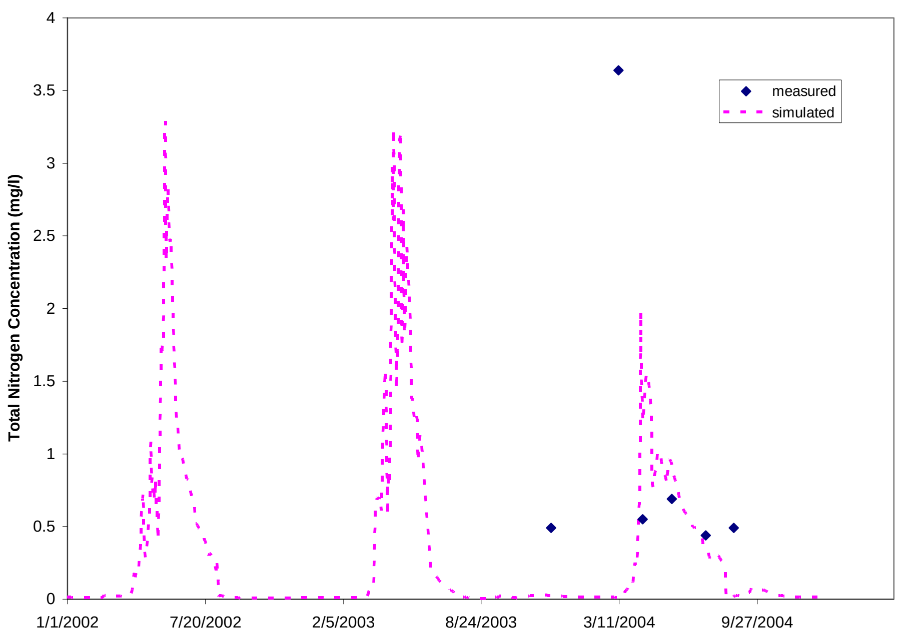

Figure D-18. Comparison of Measured Versus Simulated Total Nitrogen Concentration for Nevada Creek below the Reservoir during the 2002 To 2004 Calibration Period

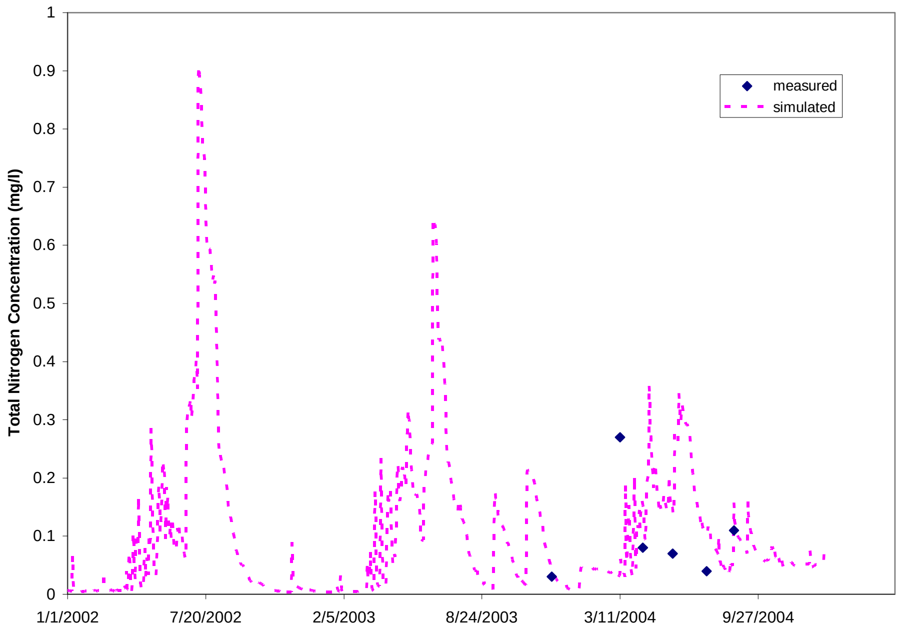

Figure D-19. Comparison of Measured Versus Simulated Total Nitrogen Concentration for the Blackfoot River above Nevada Creek during the 2002 To 2004 Calibration Period

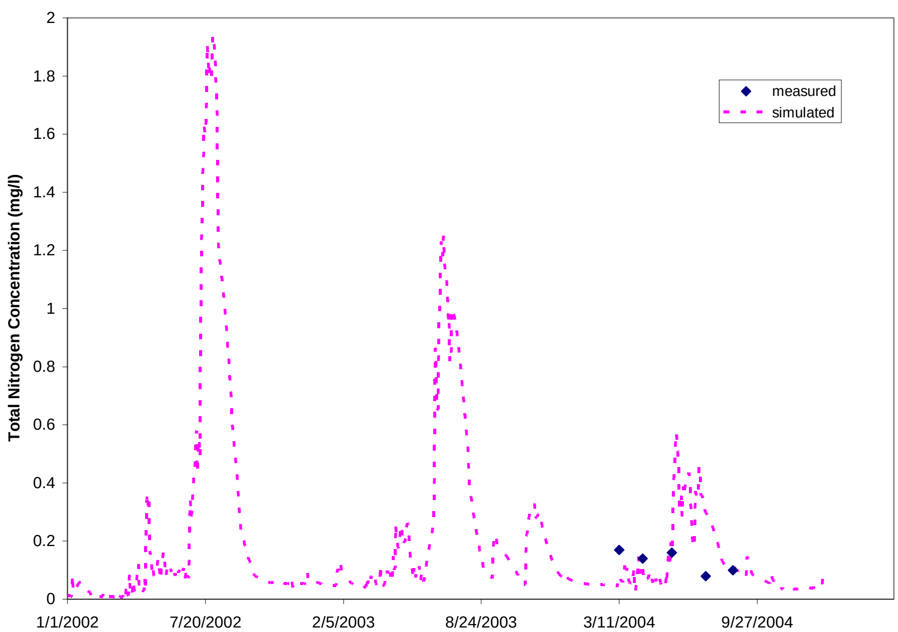

Figure D-20. Comparison of Measured Versus Simulated Total Nitrogen Concentration for the North Fork of the Blackfoot River during the 2002 To 2004 Calibration Period

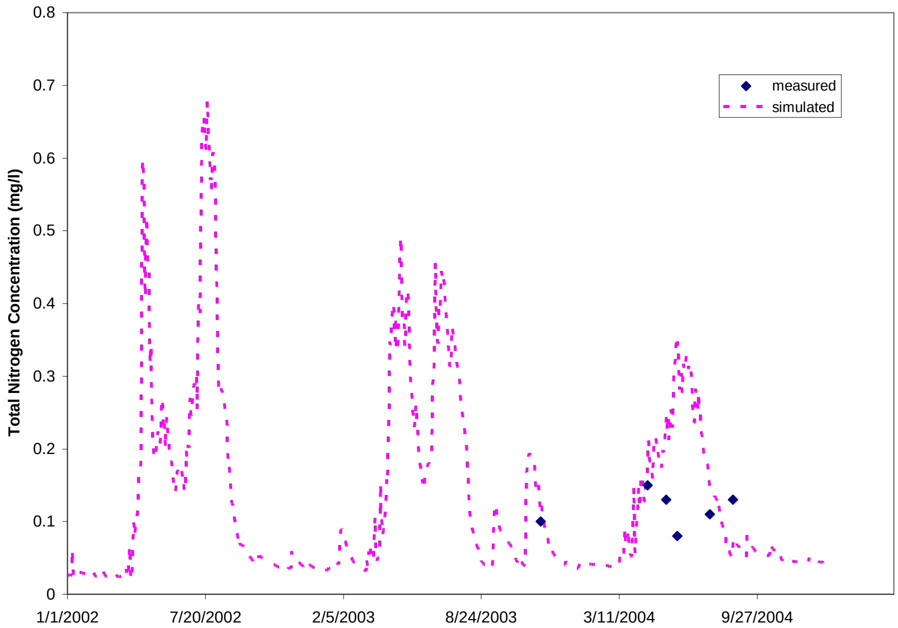

Figure D-21. Comparison of Measured Versus Simulated Total Nitrogen Concentration for the Blackfoot River at Bonner during the 2002 To 2004 Calibration Period

Figures D-22 and D-23 illustrate the inherent difficulties in calibrating total phosphorus in the Nevada Creek subwatershed. For the upper measurement point, SWAT overestimated total P, while for the lower point, the model underestimated total P. Satisfactory agreement was obtained for the Blackfoot above Nevada Creek, the North Fork of the Blackfoot River, and the Blackfoot River at Bonner.

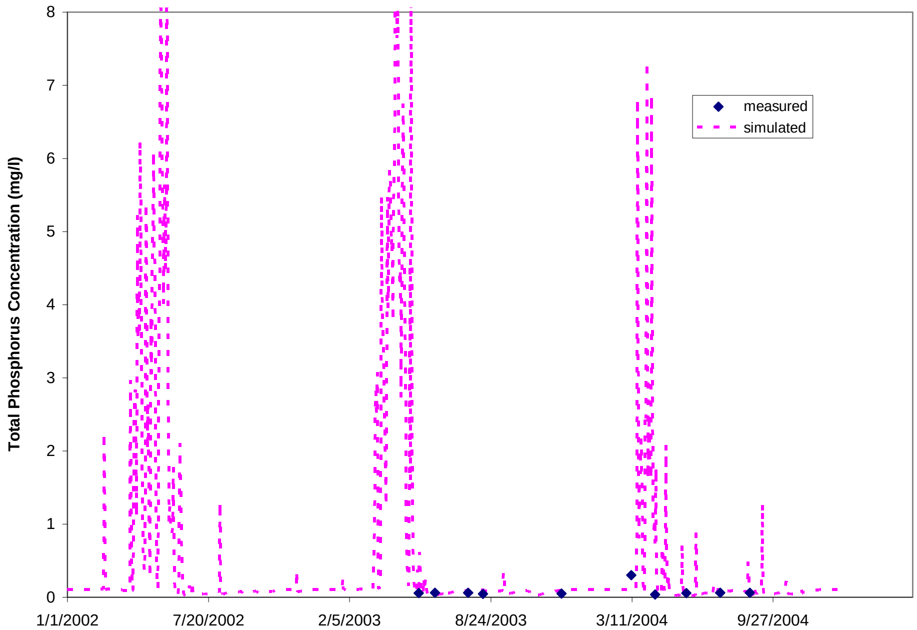

Figure D-22. Comparison of Measured Versus Simulated Total Phosphorus Concentration for Nevada Creek above the Reservoir during the 2002 To 2004 Calibration Period

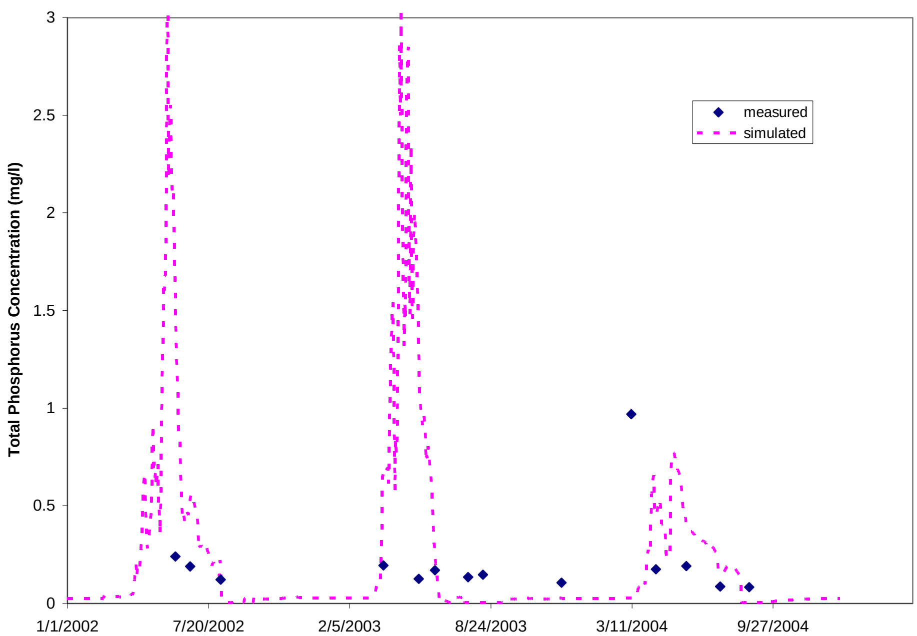

Figure D-23. Comparison of Measured Versus Simulated Total Phosphorus Concentration for Nevada Creek below the Reservoir during the 2002 To 2004 Calibration Period

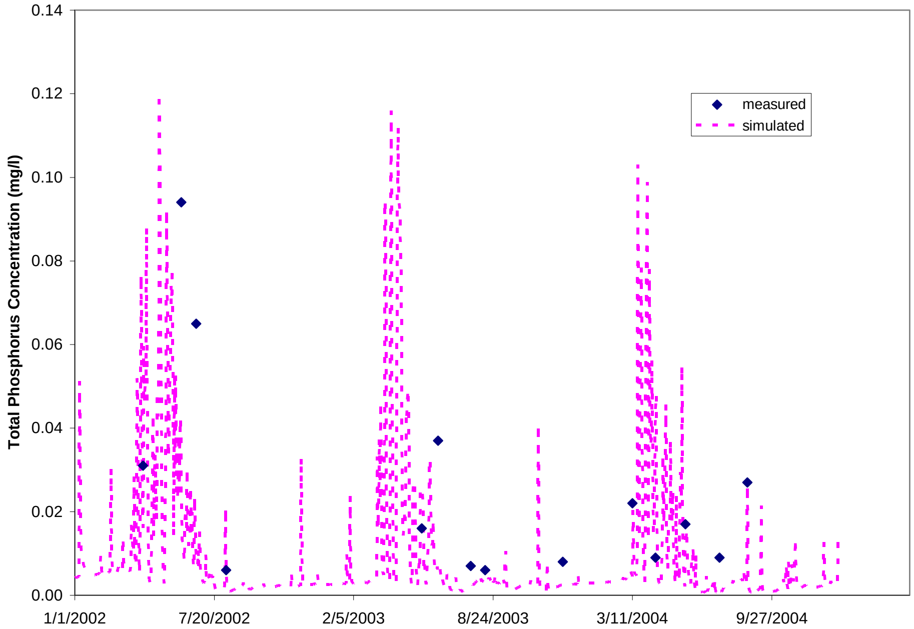

Figure D-24. Comparison of Measured Versus Simulated Total Phosphorus Concentration for the Blackfoot River above Nevada Creek during the 2002 To 2004 Calibration Period

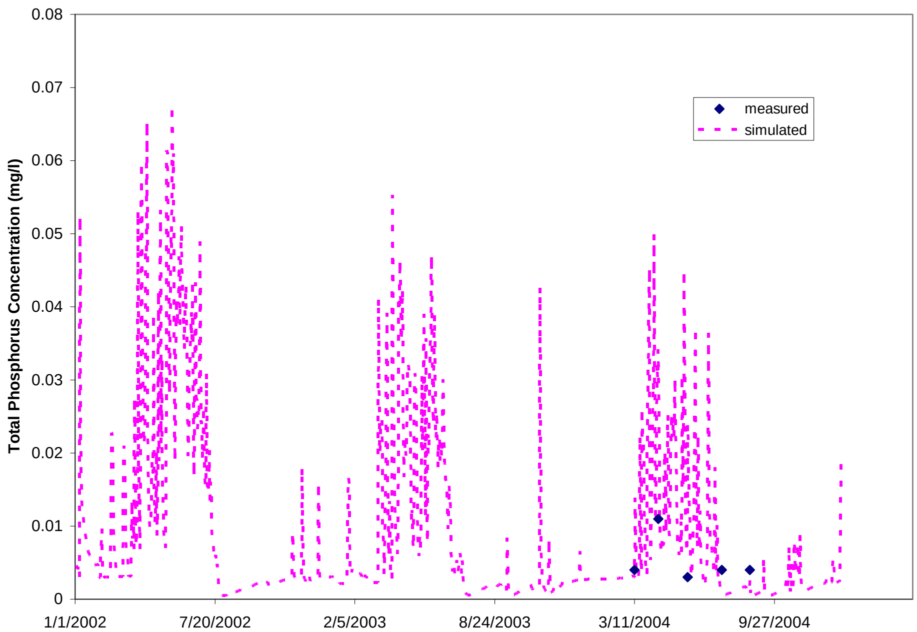

Figure D-25. Comparison of Measured Versus Simulated Total Phosphorus Concentration for the North Fork of the Blackfoot River during dhe 2002 To 2004 Calibration Period

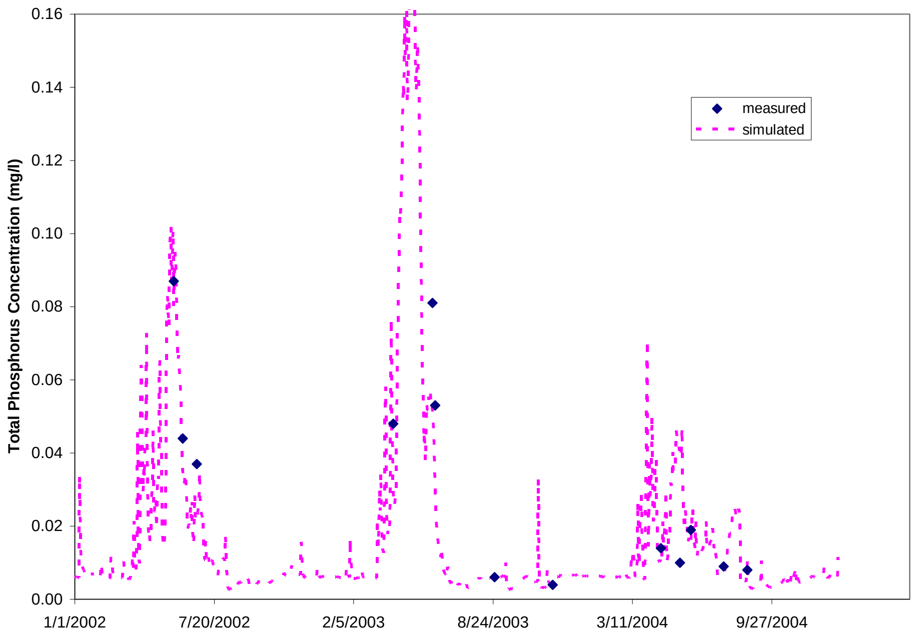

Figure D-26. Comparison of Measured Versus Simulated Total Phosphorus Concentration for the Blackfoot River at Bonner during the 2002 To 2004 Calibration Period

Shortcomings associated with nutrient calibration on the watershed were due to the limited available record, the previously described model deficiency in simulating organic versus inorganic N, and the fact that point source nutrient loading due to cattle grazing in or very near the stream was not accounted for in the model. Moderate improvement in nutrient simulation could also be achieved if regional sets of the parameters that govern nutrient transformation and movement in SWAT were utilized instead of a single set for the entire basin.

Simulation of Baseline Water Quality Conditions

Following calibration of the streamflow and water quality parameters in SWAT, a baseline period was selected for performing model simulations to represent current water quantity and quality conditions on the watershed. Simulations performed for this period not only provided estimates of sediment, total N and total P concentrations, and loadings for each of the 65 subbasins within the watershed, but also estimates of the source allocation by land cover/management type. Using available climatic and streamflow data, a 9-year period of record from 1996 to 2004 (preceded by a 5-year warm up period) was selected as the baseline condition for the Blackfoot. For this period, the annual mean, daily low flow and daily high flow are 44.1, 7.08, and 448 cms, respectively for the Blackfoot River near Bonner gage. These values compare to 44.5, 5.67, and 510 cms, respectively, for the long term record at the gage.

Daily and average annual values of water yield, sediment, total N and total P were simulated for selected stream reaches within the Blackfoot Watershed. Because output from the autocal or reach files in SWAT is not specific to particular land cover and management conditions, it was therefore necessary to use output from the HRU file in conjunction with the reach file to estimate the source allocation of water quality constituents. This was accomplished in the following manner. First, reach and HRU files were retrieved from the 9-year baseline condition. Second, SWAT was rerun without simulating the effect of channel bank and bed erosion and the reach and HRU files were again retrieved. The assumption was made that the relative proportions of sediment, total nitrogen, and total phosphorus that were simulated from the landscape for each land cover/management type would be the same as those present in the stream reaches. The estimated respective constituent fraction for a given land cover/management type assumed to be present in the stream reach was then computed by multiplying that particular simulated amount obtained from the landscape times the ratio of the total constituent reach load to the total constituent landscape load. This approach therefore provided a means for allocating a simulated load to bank/bed erosion and the various land cover/management types for a given channel reach. Results of this analysis are illustrated in **Figures D-27 through D-29**, for respective percentages of modeled sediment, total nitrogen, and total phosphorus for the Nevada Creek below the reservoir subwatershed.

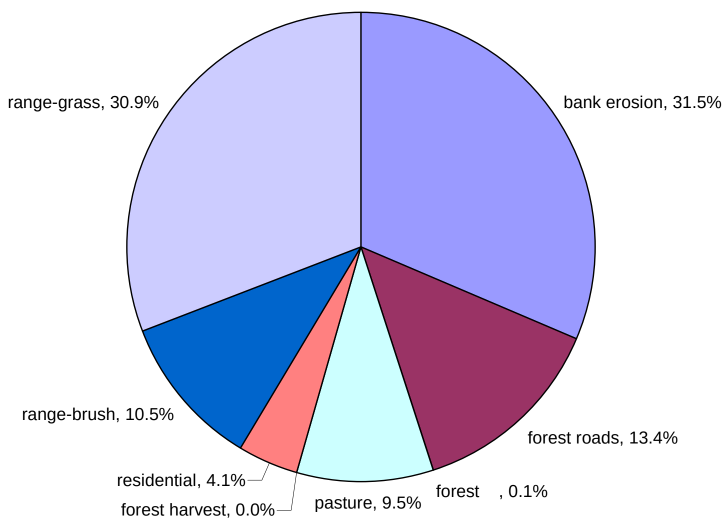

Figure D-27. Modeled Sources of Sediment for the Nevada Creek below the Reservoir Subwatershed

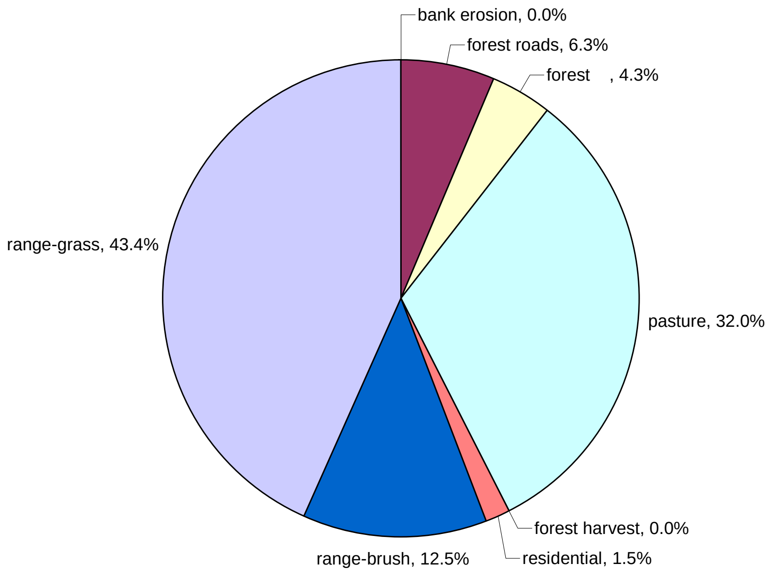

Figure D-28. Modeled Sources of Total Nitrogen for the Nevada Creek below the Reservoir Subwatershed

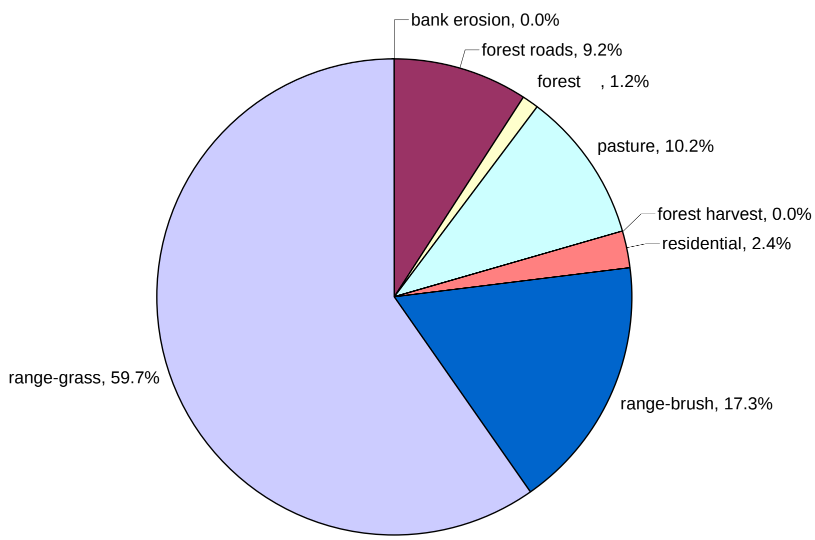

Figure D-29. Modeled Sources of Total Phosphorus for the Nevada Creek below the Reservoir Subwatershed

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